Historic, Archive Document

Do not assume content reflects current scientific knowledge, policies, or practices.

Please return
with abstract.
1F767

EMERGENCY CONSERVATION WORK

FORESTRY PUBLICATION No. 4

CONTOUR-TRENCHES CONTROL FLOODS AND EROSION ON RANGE LANDS



By REED W. BAILEY, *Director*, and A. R. CROFT, *Associate Conservationist*
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT
STATION, FOREST SERVICE, UNITED STATES
DEPARTMENT OF AGRICULTURE

EMERGENCY CONSERVATION WORK
FORESTRY PUBLICATION No. 4

WASHINGTON, D. C. MAY 1937

CONTOUR-TRENCHES CONTROL FLOODS AND EROSION ON RANGE LANDS

By

REED W. BAILEY, *Director*

and

A. R. CROFT, *Associate Conservationist*
Intermountain Forest and Range Experiment Station
Forest Service, United States Department
of Agriculture

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1937

CONTENTS

	Page
Introduction	1
Control of floods on mountain range lands an upstream-engineering problem	2
Watershed balance	2
Scope of upstream engineering	3
Purpose and description of the contour-trench system	4
Detail of the contour-trench system	4
Types of contour-trenches	4
Standard trench	4
Superstandard trench	6
Substandard trench	6
Semistandard trench	6
Application of the contour-trench system	9
Feasibility of control	9
History of run-off	9
Economic aspects of control	10
Analysis of the watershed	10
Determination of flood causes	10
Analysis of factors that affect control	11
Precipitation	11
Rainfall	11
Snow	11
Soil	12
Physiography	12
Development of the control plan	12
Sketch map needed	12
Application of the control plan	12
Personnel needed	12
Overhead	15
Labor and duties	15
Equipment needed	16
Contour-trench construction	16
Laying out trench-terraces	16
Roughing out trenches with trail-builder	17
Roughing out trenches with horses	18
Finishing	18
Inspection	21
Revegetation of trenched areas	21
Precise work essential	22

CONTOUR-TRENCHES CONTROL FLOODS AND EROSION ON RANGE LANDS

By REED W. BAILEY, *director*, and A. R. CROFT, *associate conservationist, Intermountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture*

INTRODUCTION

The Emergency Conservation Act, which became effective March 31, 1933, provided ways and means for applying measures needed to conserve and rehabilitate certain natural resources in this country which were being depleted by unwise use. A portion of the manpower which was rapidly recruited and assembled in Civilian Conservation Corps camps, including facilitating personnel, was put under the direction of the Forest Service to launch a program for the control of floods and mud-rock flows in Utah, one of the major conservation problems in the Intermountain region. The Intermountain Forest and Range Experiment Station was given the responsibility of devising the most efficient and effective methods for the control of floods and erosion originating on forest and range lands of the region.

As a result of previous research and of special studies conducted for 4 years under this program throughout the State of Utah, the contour-trench system of flood and erosion control was developed. This system has been applied effectively by the Civilian Conservation Corps on the Davis County watershed in Utah, and plans are going forward for its application in other sections of the West where floods and mud-rock flows are seriously threatening the security of dependent valley communities.

The principle of contour terracing as a soil conservation measure is very old, but the use of trenched contour-terraces on high range watersheds in the West for the prevention of devastating floods and soil losses and the method of construction represent, it is believed, a new approach in its application. The object is to get water into the ground where it falls, thus preventing surface run-off and consequent soil losses, and also to create favorable moisture conditions in the soil to hasten the restoration of the plant cover which otherwise might be too slow to meet the control problem.

The purpose of this publication is to show the relation of the contour-trench system of flood and erosion control to the broader aspects of upstream engineering applicable to the Intermountain region, to describe the system in detail, and to give instructions for its application in the field, including methods of analyzing problem areas.

CONTROL OF FLOODS ON MOUNTAIN RANGE LANDS AN UPSTREAM-ENGINEERING PROBLEM

For the past 40 years floods and mud-rock flows have been increasing in severity throughout the entire Intermountain region. Boulders, gravel, mud, and water from headwaters of steep canyons have been carried into valley communities, resulting in loss of life, severe damage to valuable farm land and suburban and industrial property, and destruction of homes and other improvements. In addition, serious social disturbances have arisen in the communities affected, because of the feeling of insecurity that has developed among the inhabitants.

The remedy for many of these devastating floods is through upstream engineering, which, in its broadest sense, includes all measures that contribute to the direct or indirect conservation of soil, water, and plant cover on high range watersheds. Upstream engineering involves the technique of land management as well as the construction of dams, reservoirs, revetments, contour-trenches, and other mechanical controls used in watershed conservation.

WATERSHED BALANCE

In developing a comprehensive program of upstream engineering, it is necessary to understand certain fundamental facts, such as the origin of soil on steep range watersheds and the relationship of plant cover to run-off.

Soil on such watersheds has formed through the ages from rock-weathering and the accumulation of decayed plant material. Vegetation plays an important part in this process, not only by contributing organic material to the upper soil horizon, but also by helping to hold the soil in place on steep slopes against the downward pull of gravity and the flow of surface waters from rain and melted snow. Without plant cover, the soil on many slopes would have been blown off by the wind or carried away by surface water as rapidly as it formed. The relationship between the stabilizing effect of vegetation and the tendency for soil to erode on steep slopes under the climatic conditions of the West constitutes a delicate balance (pl. 1).

On undisturbed watersheds this protective mantle of soil and plants exerts a marked effect on stream flow. It provides optimum conditions for the absorption of maximum amounts of rain and melted snow water, lessens surface run-off, and aids in the storage of large amounts of water in deep rock crevices, making the mountain function as a natural reservoir. Thus absorbing and storing water, it greatly reduces destructive flash-flows from melted snow water in the spring and from torrential rainstorms, and, through delayed yield, sustains stream flow during late summer. In many places, however, these favorable watershed conditions—a result of the balance or equilibrium established between slope, soil, plants, and climatic factors—have been disturbed by unwise use.

Of all the factors affecting watershed balance, the plant cover is the only one that has been materially changed since settlement. Reduction of cover—amounting to practical annihilation on critical



F324901

A NORMALLY VEGETATED WATERSHED IN THE WASATCH MOUNTAINS, UTAH.

Soil on steep range watersheds of this character has formed through the ages from rock weathering and decayed vegetable material under the protective influence of the plant cover.

PLATE 1



F293862

PLATE 2

CIVILIAN CONSERVATION CORPS WORKERS FINISHING CONTOUR TRENCHES.

The zero-grade trenches are interrupted by cross dams at intervals of 20 to 40 feet, thus making a large number of small storage units.

parts of many range-watersheds—is the direct cause of accelerated erosion on steep slopes and the disastrous floods and mud-rock flows.[1] Therefore, a comprehensive program of upstream engineering necessarily includes a consideration of the long-established natural conditions on such watershed lands, especially the important part played by plant cover.

SCOPE OF UPSTREAM ENGINEERING

These facts have led range research workers to conclude that the simplicity or complexity of a given flood and erosion control program for the Intermountain region hinges on the extent to which the plant cover has been destroyed and the possibilities of restoration. In most cases the loss of plant cover and the need for mechanical control is confined to comparatively small areas on otherwise well-vegetated watersheds. Upstream engineering efforts fall into the following general categories, depending upon the kind of measures that must be used:

1. Where sufficient native plants are available to furnish a seed supply and adequately fertile soil is present, restoration of an effective plant cover can be obtained by means of natural revegetation. This process may be hastened by the application of conservative management practices.

2. Where natural revegetation cannot be expected, owing to lack of seed, but where the soil is productive, artificial revegetation is necessary for restoring the plant cover. This may involve seeding of grasses or other herbaceous plants or the planting of trees or shrubs. Ordinarily this method of rehabilitation will necessitate complete protection from use following treatment until the vegetation is well established, or at least require a system of management which will insure the establishment and survival of the new plants.

3. Where both plants and soil fertility have been so completely destroyed that a protective cover cannot be established by natural or artificial means, the soil must be stabilized and surface run-off controlled by mechanical devices until the plant cover can be restored. These devices fall into two groups: Those that offer a direct method of attacking the problem of flood prevention by controlling run-off from precipitation by means of contour-trenches, lakes, or small upland reservoirs; and those that offer indirect methods of attack, including such counteractive measures as check dams to establish new base levels in rejuvenated channels, and revetments to stabilize the banks of these channels.

The present discussion is limited to that phase of upstream engineering which involves the use of contour-trenches for controlling mud-rock flows, floods, and soil losses by restraining flash run-off and facilitating revegetation.

---

[1] Bailey, R. W. Shackling the Mountain Flood. Amer. Forests 41(3): 101–104, 150, illus. 1935.

——— Forsling, C. L., and Becraft, R. J. Floods and Accelerated Erosion in Northern Utah. U. S. Dept. Agr., Misc. Pub. 196, 22 pp., illus. 1934.

United States Department of Agriculture, Forest Service. A National Plan for American Forestry. 2 v., illus. 1933. ([U. S.] Cong. 73d, 1st sess., S. Doc. 12.)

——— The Western Range. 620 pp., illus. 1936. ([U. S.] Cong. 74th, 2d sess., S. Doc. 199.)

PURPOSE AND DESCRIPTION OF THE CONTOUR-TRENCH SYSTEM

The contour-trench system has been applied with the realization that it is more or less temporary and that plant cover will eventually be restored to such an extent that it will regulate run-off and stream flow and hold the soil in place. Contour-trenches are effective in meeting the immediate problem of run-off and erosion control and the ultimate problem of restoring a protective plant cover because (1) all the water that falls on a trenched area is absorbed, thus preventing flash run-off and destructive floods and improving soil-moisture conditions which stimulate plant growth; (2) erosion losses are checked, thus improving soil stability, which is also necessary for plant growth; and (3) the type of trench used can be constructed with a minimum of soil disturbance, as the maximum cut is not more than 5 and 9 inches respectively for semistandard and standard trenches.

DETAIL OF THE CONTOUR-TRENCH SYSTEM

Studies show that on denuded steep slopes on the Davis County watershed as much as three-fourths of the total precipitation may run off while only one-fourth is absorbed. The contour-trench system, as developed and successfully applied here, consists of a series of zero-grade trenches having about 200 compartments or reservoirs per mile of trench and spaced close enough together to hold about 75 percent of the precipitation that falls between them (pl. 2).

The system provides for the storage of water in small individual units and the movement of water from one unit to another. This is accomplished by placing low cross dams, called equalizers, at right angles to the trench axis at intervals of 20 to 40 feet, so that each trench functions as a large number of small storage units rather than as one single unit. These equalizers are 0.3 foot lower than the fill dike, which allows water to flow from one section to another without overtopping the dike. This provision permits the movement of water from areas of excessive run-off, such as snowbanks or small gullies, to adjacent sections of the trench where it can be absorbed. Water may also be diverted gradually along an entire trench length into rock talus, dense plant cover, or larger storage reservoirs.

TYPES OF CONTOUR-TRENCHES

Because of the highly varied conditions of soil and slope that are encountered on mountainous watersheds, no one type of trench has been found suitable to meet all conditions, although the design is fundamentally the same for each trench. The following types of trenches have been found successful in preventing floods on the range watersheds of northern Utah:

STANDARD TRENCH

A standard contour-trench is one with cut-and-fill slopes not steeper than 1½:1 and having sufficient capacity to hold 75 percent of the run-off from a 2-inch storm, allowing a 0.2-foot freeboard, when the horizontal interval between trenches is about 25 feet (fig. 1, *A*).

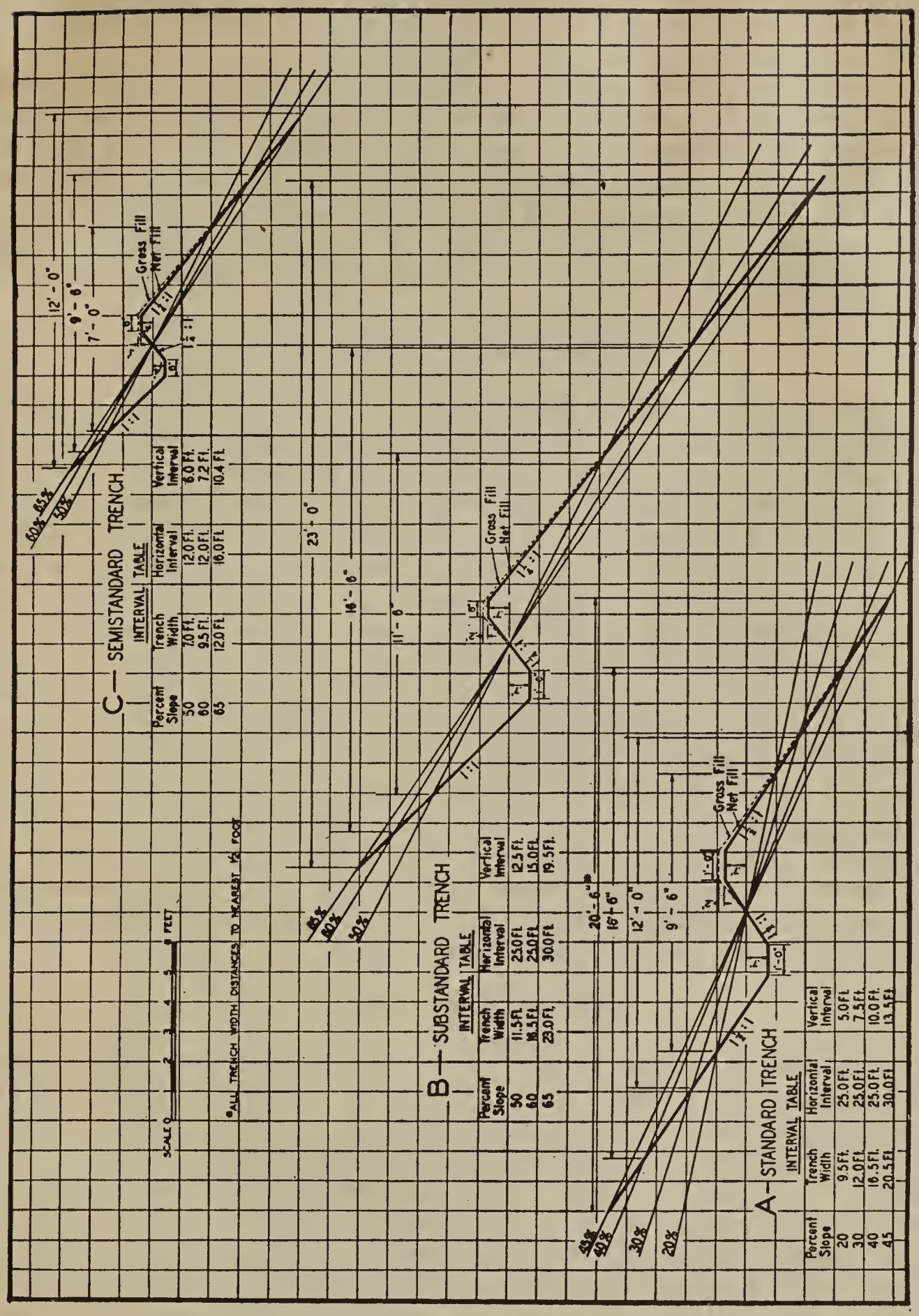


FIGURE 1.—Trench specifications for various slopes.

135088°—37——2

When the fill dike has settled about 15 percent, this trench is 1.4 feet deep. It is feasible to construct trenches of these specifications on slopes up to 40 percent, which will provide adequate protection against run-off during torrential storms such as occur in northern Utah. Moreover, the cut-and-fill slopes are stable and therefore are conducive to long life for the structure as well as to the revegetation of the disturbed soil.

The standard trench may be used on 45-percent slopes with a 25-foot interval by checking the toe of the fill with rocks, brush, or logs, which obviates danger of dirt from the dike of a trench-terrace filling the trench below, but this practice greatly increases hand labor. The trenches can be used without toe checks if they are spaced at 30-foot intervals. Under the latter conditions the trench freeboard is reduced to 0.1 foot during maximum run-off from a 2-inch storm.

SUPERSTANDARD TRENCH

A superstandard trench is one constructed to the same cut-and-fill slope specifications as the standard trench, differing only in that its capacity is increased from 2 to 10 times, depending upon the size of the area from which run-off is expected. These oversize trenches are used: (1) To equalize the run-off from deep snowbanks where from 40 to 200 inches of melted snow water is released at a rate sufficient to destroy trenches of ordinary capacity, thus leaving such areas unprotected against heavy summer precipitation (fig. 2); (2) to protect against flood run-off from rock outcrops; and (3) to protect against run-off from steep slopes where semistandard trenches have been constructed or where steepness of slope prevents mechanical treatment of any kind (fig. 3).

Because of the relatively large amount of soil disturbed, supertrenches should be located so far as possible on slopes of less than 30 percent. One end, sometimes both ends, should terminate in dense brush, timber, talus slopes, or in small catchment basins, to which small quantities of water in excess of the absorbing capacity of the trench may be safely diverted.

SUBSTANDARD TRENCH

A substandard trench is one with cut-and-fill slopes of 1:1 and 1¼:1, respectively, and with a fill section of only 6 inches at the top, having slightly less capacity than the standard trench. When standard trenches are modified in this manner they may be constructed on slopes as steep as 60 percent without increasing the horizontal interval (fig. 1, *B*). Theoretically, this type of trench can be constructed on 65-percent slopes by increasing the horizontal interval to 30 feet, but construction difficulties are increased to such an extent that it is impractical, if not impossible, to do so under the conditions found on these steep areas.

SEMISTANDARD TRENCH

A semistandard trench, which is only 0.8 foot deep, has cut-and-fill slopes of 1:1 and 1¼:1, respectively, with sufficient capacity to hold about 50 percent of the expected run-off from a 2-inch rain-

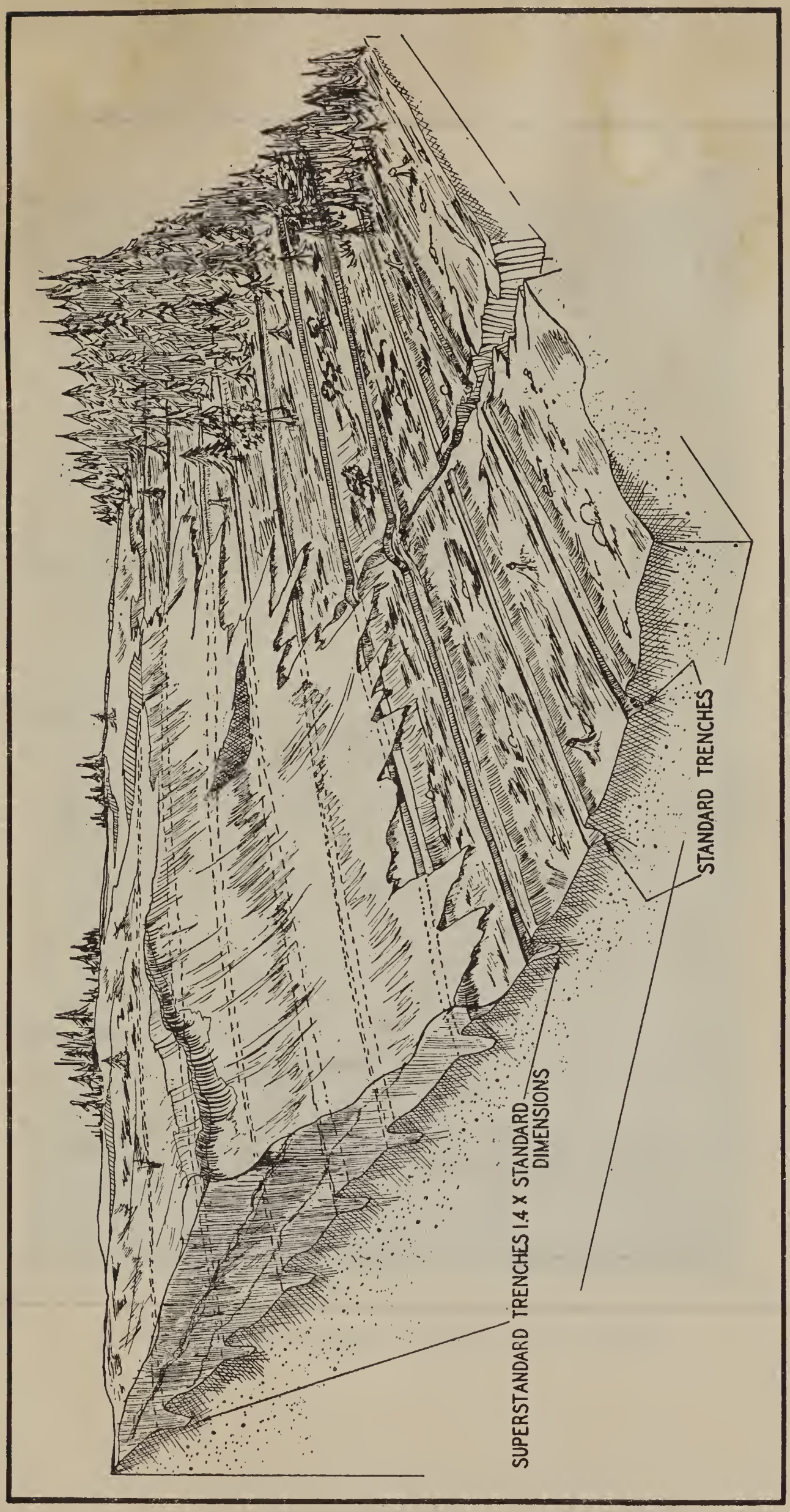


FIGURE 2.—Snowdrift over trenches in late spring.

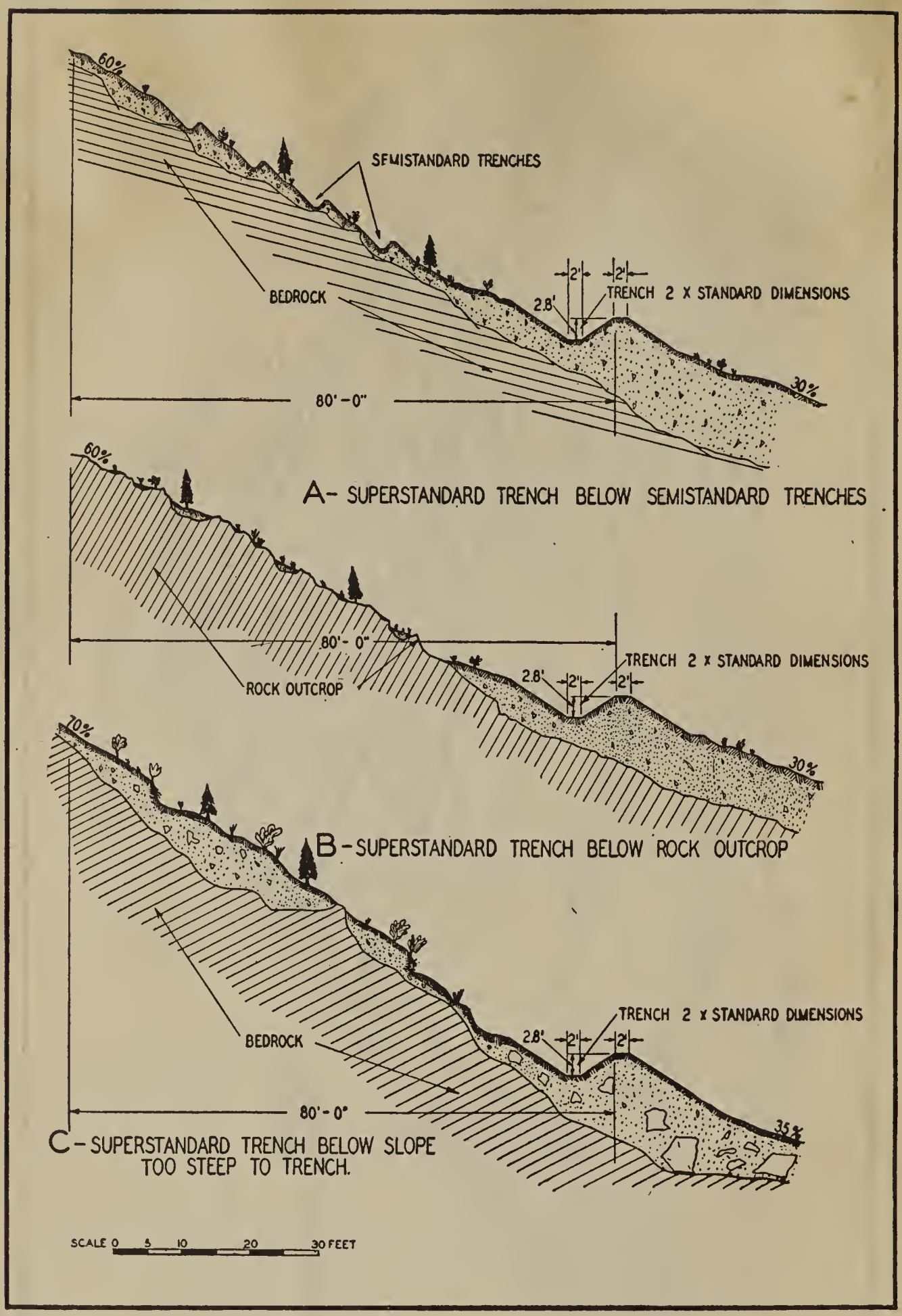


FIGURE 3.—Trench plans for special slope conditions.



F326415

THE CLOSE RELATIONSHIP OF WATERSHEDS AND VALLEY COMMUNITIES IS HERE ILLUSTRATED.

When the vegetative cover is destroyed on even small parts of mountains, floods and mud-rock flows may follow. A C. C. C. camp may be seen in the right foreground.

PLATE 3



F324856

Deep gullies cut into well-aggraded canyons head back to bare spots or erosion "islands", such as that indicated by the arrow, that produce devastating run-off during torrential rainstorms. Contour trenches are visible on some bare spots.

PLATE 4

storm of about 1-hour duration when a 0.2-foot freeboard is allowed and trenches are spaced 12 feet apart (fig. 1, *C*). These trenches are adaptable to steep slopes above 50 percent where construction difficulties such as shallow soil, boulders, and rock outcrops are encountered. Although they do not meet standard capacity requirements they prevent all the surface run-off from normally heavy storms and flood run-off from the heaviest storms of so-called cloudburst intensity. Construction of this type of trench on steep slopes may be justified, also, because it stabilizes the seedbed and improves soil moisture conditions, thus hastening the restoration of a protective plant cover.

APPLICATION OF THE CONTOUR-TRENCH SYSTEM

When it is determined from a study of the history of stream flow and the economic and social values involved that control is feasible, the application of the contour-trench system to a specific problem area consists of (1) analysis of the watershed to determine the origin and causes of floods; (2) analysis of the physical factors of the watershed that affect the control plan; (3) development and application of the control plan; and (4) revegetation of the controlled area.

FEASIBILITY OF CONTROL

HISTORY OF RUN-OFF

The history of run-off from a flooding stream should be determined as accurately as possible in order to compare its current behavior with that at the time of settlement and for as long before that time as its record can be accurately interpreted. This comparison should indicate whether floods are natural and common occurrences or phenomena new to the area since settlement.

If floods and mud-rock flows have been frequent during the period since settlement, this fact may be ascertained from inhabitants of the area, and their testimony may be checked by a study of local conditions. For example, undisturbed homes, farm land, power and irrigation developments located along stream channels indicate that destructive floods have not occurred during the period since their establishment. On the other hand, recent radical disturbances of these cultural developments by floods indicate a change in the factors which hitherto controlled the character of stream flow from the watershed.

This stream-flow history can be projected back into the immediate geologic past by studying the kind and character of material deposited in stream deltas, if present, and over the surface of the alluvial fan built up by the stream. If the materials in these deposits, together with the testimony of the local inhabitants, indicate that floods are common and have always occurred, there are only slight possibilities of applying effective control measures. However, if the data collected show that floods were uncommon before settlement and for some years after, then the application of control measures may be feasible.

ECONOMIC ASPECTS OF CONTROL

Control of erosion on range watersheds by mechanical means is obviously an expensive process, and justification naturally hinges upon the economic and social needs for protection as well as on the feasibility of preventing devastating floods. Thus far the Forest Service has confined the use of this system to the most critical spots on badly depleted drainages where the investments in rural, urban, and industrial property in the adjacent valley flood zones justify the expenditure of from $25 to $50 per treated acre. These control costs are not given as a fixed basis for approving or disapproving a given project, for each control program must be justified on its own merits.

Many situations exist, no doubt, where investments in endangered adjacent communities, towns, and farms, and the value for irrigation and power of regulated stream flow are so great that effective control of flood waters at any cost may be desirable (pl. 3). In some localities water for domestic, industrial, and agricultural uses is 10 to 100 times more valuable than the watershed lands from which it comes. However, watershed soil is one of the most important of the factors on which the perpetuity of the adjacent valley communities depends. The soil resource of watershed lands influences directly or indirectly most of the usable assets of these areas, such as forage, timber, quality of water yield, game, and recreation. Because of the thousands of years necessary for the formation of this basic asset and because of the speed with which it is being altered or even lost from steep slopes of certain watersheds, application of control measures on critical areas is justified.

ANALYSIS OF THE WATERSHED

DETERMINATION OF FLOOD CAUSES

If floods or mud-rock flows are determined to be a recent radical departure from the normal flow characteristic of the drainage, this is substantial evidence that a critical situation exists on the adjacent watershed. The first step in determining flood causes is to find where the flood waters originated. Deep gullies cut into well-aggraded canyons can be followed back almost without exception to the areas which produced excessive run-off. These areas are usually found to be spots, or "islands", on an otherwise well-vegetated watershed. On watersheds that have permanent streams which originate in high altitudes, these islands may constitute as little as 2 percent and commonly do not exceed 10 percent of the total area (pls. 4 and 5).

Erosion "islands" have the following specific earmarks: (1) Badly depleted or complete loss of plant cover as compared with adjacent well-vegetated areas; (2) absence of organic soil comparable to that on similar adjacent areas; (3) numerous shallow gullies uniting to form larger and larger gullies in very short distances; (4) fine gravel, pebbles, or rocks, known as erosion pavement, concentrated on the surface; and (5) pedestaled plant clumps whose crowns, or ground bases, are elevated above the interplant spaces.

These areas usually show unmistakable evidence of destructive utilization, which in the Intermountain region is largely in the form of overgrazing. This excessive localization of depletion is influenced by (1) the nature of the vegetation (open grass and shrub types are easily accessible to livestock grazing as compared to dense brush and timber); (2) the presence of stock-watering places; (3) topographical features favorable for the natural congregation of cattle and for bedding sheep; and (4) snowbank areas which have become denuded because of the short growing season and excessive trampling by cattle and sheep.

ANALYSIS OF FACTORS THAT AFFECT CONTROL

PRECIPITATION

The contour-trench system is intended primarily to prevent flood run-off from barren slopes during torrential rainstorms, but trenches must also be designed and constructed to prevent serious damage from large quantities of water from rapidly melting snow.

RAINFALL

Rainfall data on many areas needing control will, no doubt, be lacking, but records obtained from the nearest rainfall stations may be used as a guide to control design by taking into consideration the fact that rainfall is greater in the mountains than in the valleys. In the Intermountain region, experience has proved that it is wise to design trenches that will hold at least 75 percent of the run-off from torrential rainstorms of 2 inches per hour. Trenches constructed to meet these conditions will be excessively large for more than 95 percent of all rainstorms, but it is the infrequent storm of unusually high intensity and short duration that produces high run-off with devastating results. The resultant run-off observed during torrential storms on the Davis County area during the summer of 1936 demonstrated that the standard contour-trenches described herein should be constructed wherever possible in the Intermountain region if maximum flood prevention is to be assured (pl. 6, *A* and *B*).

SNOW

The accumulation of snow in great drifts that yield water for 1 to 3 months after spring run-off begins is a problem, especially where flood danger has been accentuated by depletion of vegetation, that must be met by the construction of even larger trenches than are necessary to prevent run-off from torrential summer rainstorms. Supertrenches constructed to precision standards which enable melted snow water to flow over the equalizers and along the trench to adjacent areas where it can be absorbed are shown in figure 2.

The nature and extent of the snow problem can be determined only by frequent visits to critical areas after run-off begins. This is a highly important phase of the planning program, because trenches constructed on snowbank areas may be so damaged by spring run-off that they will be useless for flood prevention during torrential summer rainstorms (pl. 7).

SOIL

In general, areas having soil which can be worked with "bulldozers" or "tractor trail builders" and plows are satisfactory for trench construction.

Areas which have 12 to 18 inches of soil development above the unaltered parent material can be trenched successfully without exposing the sterile substratum which is unfavorable for plant growth and which may have practically no stability for trench construction. Test holes should be dug at random intervals on each work area with a trenching tool or other convenient device to determine the nature and depth of the soil. It is further recommended that a few short test trenches be made by hand if necessary and allowed to remain over winter to see if they will hold up under existing soil and slope conditions.

PHYSIOGRAPHY

The contour-trench control system described was developed especially for steep range-watersheds having elevations of from 7,000 to 10,000 feet where slopes vary from 20 to 60 percent. Although these specifications apply particularly to such areas, the system may be adapted to any physiographic conditions where sufficient soil depth exists and where slopes permit construction.

DEVELOPMENT OF THE CONTROL PLAN

SKETCH MAP NEEDED

A control work plan for each area should be drawn up on the ground by the technician who is to supervise the program. Each plan should consist of a large-scale sketch map of the work unit, which should show as illustrated in figure 4: (1) The work-unit drainage boundary; (2) the boundaries of all areas within the unit on which run-off conditions are satisfactory and of those which need control; (3) the locations of snowbank areas, rock outcrops, cliffs, talus, and other physical features which may have an accelerating or retarding influence on surface run-off; (4) the location of gullies and the treatment needed; and (5) the type of trench to be constructed on each area. Figure 5 illustrates the application of the work plan on a specific area.

Because of the large amount of information required, the map should be drawn to a scale of not less than one-fourth inch per 100 feet. To aid the foreman in interpreting the map, flags are placed on the work unit to indicate the boundaries of areas and gully sections to be trenched and location of special types of trenches.

The map should be accompanied by a statement indicating the kind of equipment needed to do the job, service roads needed to make the area accessible, and the estimated time necessary to complete the work.

APPLICATION OF THE CONTROL PLAN

PERSONNEL NEEDED

Recommendations for the personnel needed to make a practical working unit as described herein for contour-trench construction are based on 4 years' experience with the Civilian Conservation Corps



F253171

A close-up of the erosion "island" indicated by the arrow in plate 4, showing depleted plant cover and extensive sheet and gulley erosion.



F331564 F331565

A, Showing water in trenches 2 hours after a rainstorm of 1.15 inches that fell in less than half an hour. *B*, Close-up view of trenches holding water on a 30-percent slope. Run-off from untreated slopes of comparable conditions was about 75 percent during the storm. Water thus held in 90 miles of similar trenches on about 600 acres on the Davis County watershed prevented serious floods during torrential rainstorms in the summer of 1936 from watersheds which had flooded in previous years.

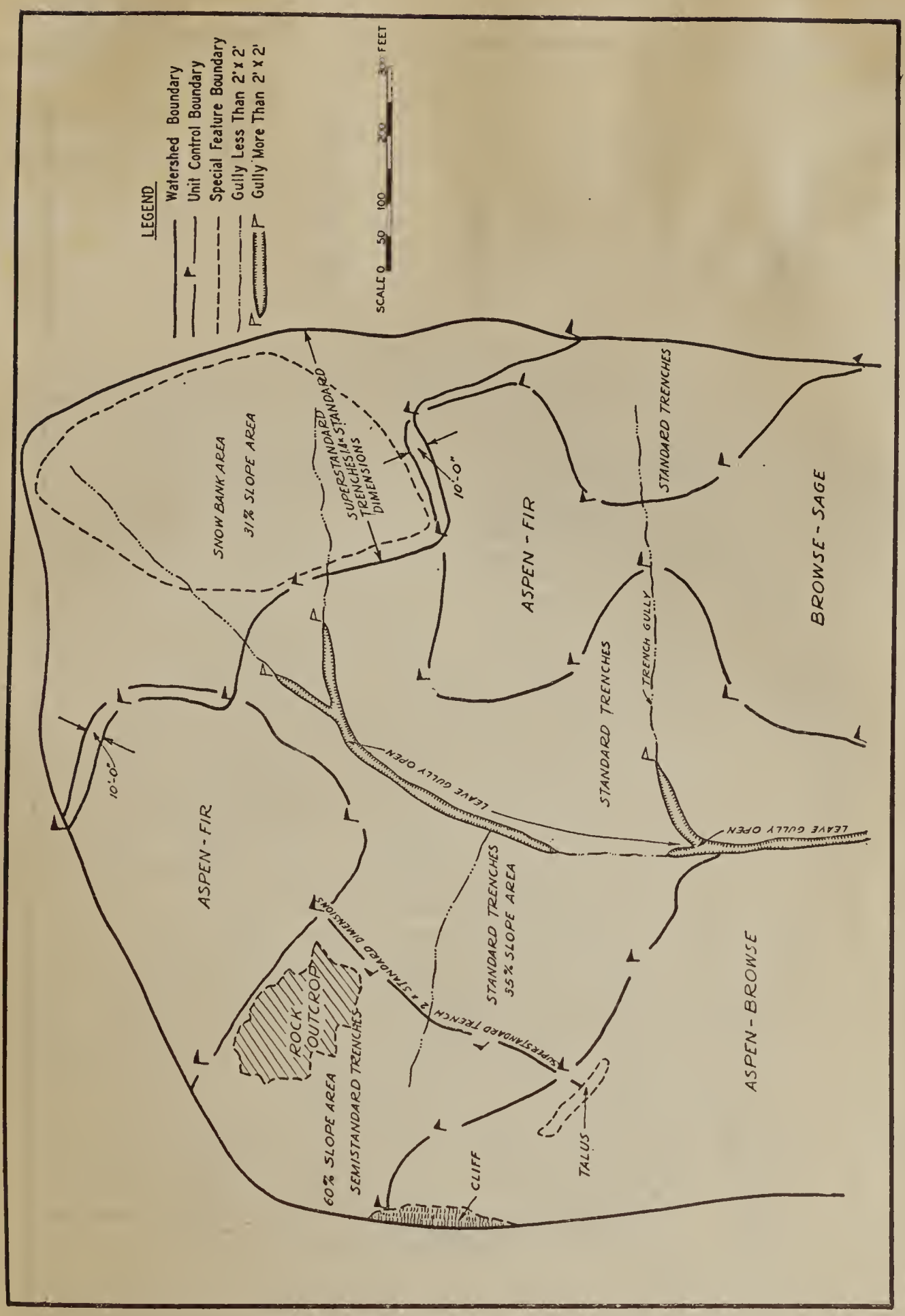


FIGURE 4.—Work plan sketch for drainage unit control.

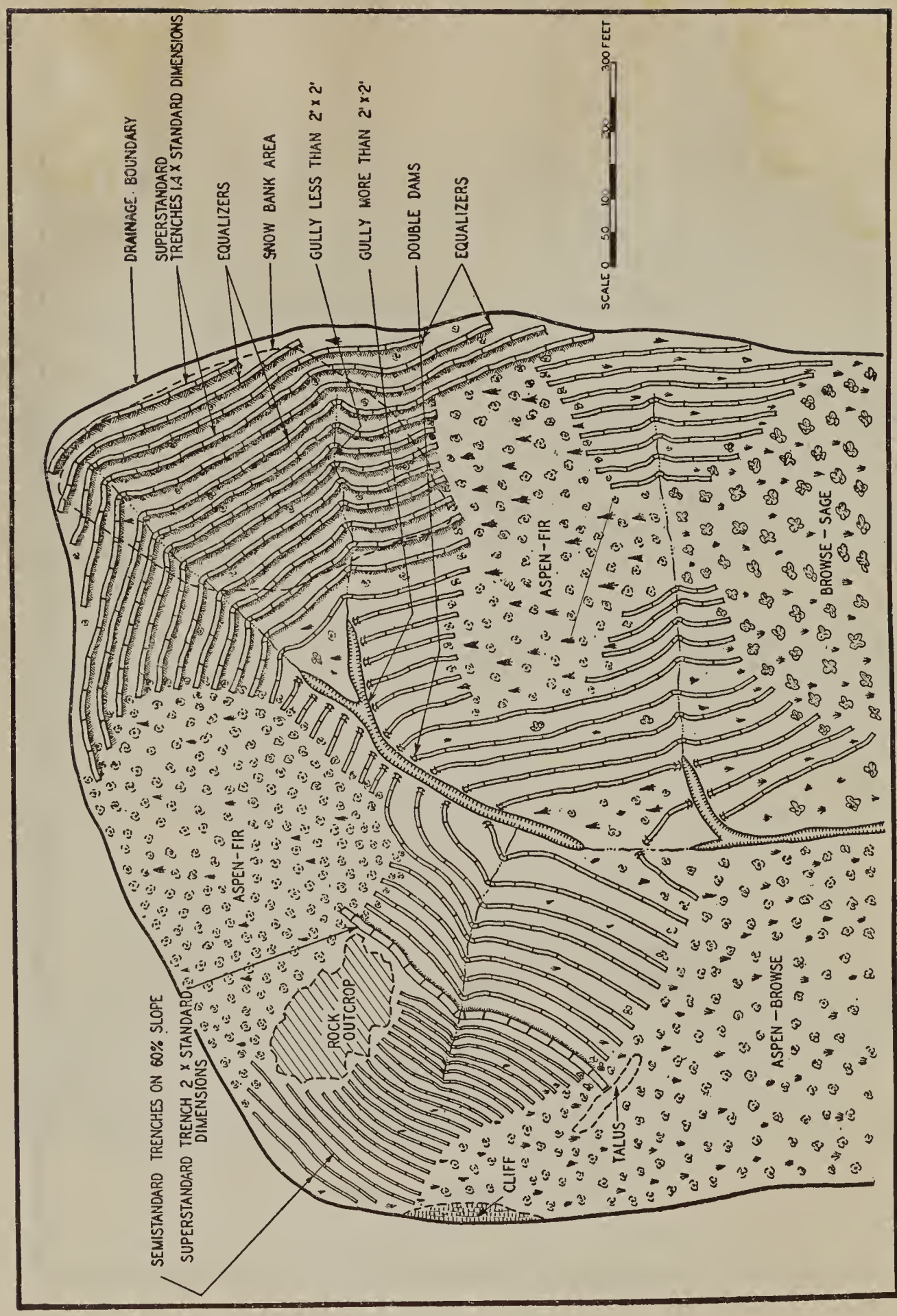


FIGURE 5.—Applied plan for drainage unit control.

and the average type of labor and overhead available. The number of men recommended is based on the use of one trail-builder and one or two teams, depending on the percentage of the area that is too steep for tractor work.

OVERHEAD

The overhead which will produce best results for this working unit consists of *one engineer-technician* and *two foremen* who will devote their entire time to the job. The engineer-technician should be capable of assuming full responsibility for the work, and should have an average knowledge of engineering, of range plants, and of practical erosion problems. The handling of running water under ordinary circumstances is a difficult task, and on the steep depleted slopes where this work is usually done, the difficulties are multiplied, so that need for capable supervision in all phases of the plan is apparent.

Division of responsibility.—It has been found that a definite division of responsibilities in the overhead results in the most economical and satisfactory work. The responsibilities of the engineer-technician will be to plan the control program, supervise the crew foreman, inspect the construction, and approve each work unit after it has been brought up to accepted specifications. Responsibility of the foremen consists of supervision of the machines and labor in the execution of the work plan.

One of the foremen should be assigned to the finishing crew and the other should be given supervision of the trail-builder. This latter assignment is an economical practice, for if the machine is allowed to "sag" at various points on the contour, stop short of its indicated goal, cross gullies without providing adequate fill, or if it fails to make the rough cut deep enough, an excessive amount of hand labor may be necessary for completion. Careful supervision of machines by a foreman will eliminate most of these troubles which may result in an additional amount of machine work equal to that which may be done by 20 to 30 hand laborers. Close supervision will, of course, become less necessary as tractor operators become more skillful and learn what their job is intended to accomplish. A tractor operator who has had the arduous assignment to finish with a shovel poorly roughed-out trenches, will probably be a good prospect for an operator.

LABOR AND DUTIES

The division of laborers into the following crews with duties as indicated has been found practical:

1. *Engineering or leveling crew:* 1 levelman, 1 rodman, 1 stakeman.

The duties of this crew are to place the primary grade stakes, which guide the roughing-out operations, and the final grade stakes as guides to the finishing crew.

2. *Tractor crew:* 1 operator, 1 helper.

The duties of this crew consist of roughing-out the trenches, with particular attention to maximum machine labor and eliminating all possible hand labor.

3. *Team crew:* 2 teamsters, 1 plowman, 2 ditchermen, 2 stablemen.
4. *Finishing crew:* 30 men.
5. Truck driver.

EQUIPMENT NEEDED

The following equipment is needed for the personnel listed:

1. *Engineering unit:* 1 engineer's level, 2 Locke hand levels, 1 leveling rod, 1 hand ax, 1 stake bag, 1 box keel, 1,000 lath.
2. *Tractor unit:* One 55-horsepower crawler type tractor with adjustable blade attached on front (trail-builder).
3. *Team unit:* Two 3,200-pound teams, 2 sets double harness with collars, two 12-inch reversible moldboard plows, 2 ditchers with 4-foot blades, 8 tug chains, 2 sets doubletrees, 4 heavy duty clevises, three ⅜- by 24-inch chains.
4. *Finishing crew:* 30 shovels, 6 picks, 1 tool box.
5. Truck for tractor fuel, oil, supplies, and equipment.

CONTOUR-TRENCH CONSTRUCTION

The construction of contour trenches involves four steps including (1) laying out, (2) roughing out, (3) finishing, and (4) inspection.

LAYING OUT TRENCH-TERRACES

In laying out the trench plan several important phases of the work require special attention in order to insure a high standard in the completed unit. These phases include the placing of grade stakes, adjusting the horizontal interval to changing slope conditions, and locating stakes in crossing gullies to eliminate unnecessary hand labor.

Placing grade stakes.—The placing of grade stakes for the first trench should start on the area farthest from the base of operations to prevent travel of equipment and crews over finished or partially finished trenches. The grade line for the first trench should be determined and marked by stakes showing about 2 feet above the ground at 16-foot intervals. Spacing stakes at distances greater than 16 feet may allow construction machinery to "sag" between stakes, requiring extra hand labor to bring the trench up to grade.

An engineer's level should be used to lay out all trenches where the slopes and soil are uniform, because machines can follow grade very accurately under such conditions. A Locke hand level may be sufficiently accurate on rocky areas where, at best, it is difficult for machinery to keep on grade. *Do not use an Abney type hand level* because it gets out of adjustment easily, causing serious inaccuracies in grade.

After the first trench is staked on grade the process is repeated for succeeding trenches. An interval appropriate for the kind of trench being constructed and in accordance with the percent of slope should be used, as indicated in figure 1. After the slope is known for a given area, the starting point for each additional trench may be determined by measuring the proper vertical distance above or below the last trench. For example, if the slope is 30 percent, the most convenient method of spacing the next trench at a 25-foot horizontal distance is to measure vertically up or down hill 7.5 feet.

Change of horizontal interval.—When trenches are staked out on zero grade commencing with given slopes and horizontal intervals, they are built closer together or farther apart as the slope increases



F316677

PLATE 7

TRENCHES DAMAGED BY RUN-OFF FROM MELTED SNOW.

This damage may be prevented by precision construction.



F308657 F293865

ROUGHING OUT CONTOUR-TRENCHES.

A, Trail builder at work. The blade is set at a slightly steeper pitch than the working slope. *B*, Horses furnish convenient power for use with plows on steep, rocky slopes.

or decreases. If the slope varies between any two adjacent trenches sufficiently to make a sustained change in horizontal interval of 25 percent, this variation is accommodated by stopping the trench and moving up or down hill the necessary distance to obtain the proper horizontal interval. In the case of decreasing slopes where the interval is increased only locally, it may be more practical to continue the original trench on grade and locate, where the interval is excessive, an additional stub-trench.

Staking trenches through gullies.—The problem of crossing gullies with trenches is a matter that must be left largely to the discretion of the technician. However, the following rules have been found very helpful in emphasizing certain principles involved:

(1) Starting at the head, trench across all gullies as long as this can be accomplished on grade without excessive filling by hand labor. Ordinarily, it will be found practical to cross gullies up to 2 feet in depth and width.

(2) Stop trenches on either side of a gully larger than 2 feet by 2 feet.

(3) When trenches are once stopped at the gully edge, do not cross it again at a point lower down than three trench intervals even though the gully becomes small enough to do so, since it is very probable that the increased interval will produce more run-off than can be stored without overtopping, resulting in the eventual loss of the gully section.

(4) For guidance during construction of trenches across gullies, place one stake on each gully bank on grade and a third stake 1 foot horizontal distance above the contour point in the bottom of the gully. The deviation from the contour point by the upper gully stake is to provide fill material in extending the trench across the gully and to compensate for the tendency of the machine to slide down hill as it crosses the depression.

ROUGHING OUT TRENCHES WITH TRAIL-BUILDER

The most practical and economical method of roughing out trenches is with a crawler type 55-horsepower tractor and trail-builder combination with a low center of gravity. Tractors can be used effectively by skilled operators on slopes as steep as 35 to 40 percent. This kind of equipment makes a large rough cut most nearly approaching the shape of finished trenches, thus requiring a minimum of hand work; it throws a larger amount of dirt into the fill dike; it is easy to get into the work areas; it will operate in coarse rocky soil handling large rocks and decadent stumps that would be difficult for teams to remove; and it can be operated at a relatively low cost. Tractors cannot be operated effectively on slopes greater than 35 to 40 percent, and in gullied terrain they are not capable of making the sharp turns necessary to maintain zero grade.

For use in contour-trench construction the blade of the trail-builder is set at a slightly steeper pitch than that of the working slope (pl. 8, *A*). A few trials will be necessary to get the proper adjustment.

It has been found practical to move the tractor forward and backward, cutting only on the forward trip, unless conditions are unusually favorable for turning and readjusting the blade after each

trip along the trench line. The economy of the latter operation will depend largely on the length of the trenches and the slope on which they are being constructed. Ordinarily, about three forward trips are necessary to throw the maximum amount of dirt into the fill that can be moved by the conventional trail-builder blade. Where slopes are not more than 30 percent, the lower machine track may be laid down on top of the fill section on the backward trip without danger of upsetting the tractor in case it should slip downhill onto the steep pitch of the fill. This operation aids greatly in packing the fill section, and thus in constructing a more stable trench.

As the trench is being roughed out, the operator's helper should follow closely behind the machine, removing brush, stumps, and other coarse material that may be thrown into the dike. This material is removed to prevent honeycombing the fill section, which might result in leakage and finally in the destruction of the trench section in a short time.

ROUGHING OUT TRENCHES WITH HORSES

Horses provide the best mode of power on slopes greater than 40 percent or where tractors may not be usable for any other physical or economic reason (pl. 8, *B*). Plows with convertible moldboards, supplemented by ditchers of suitable type, have been found satisfactory for putting a large amount of fill material into place preparatory to hand finishing. Horses should be worked abreast as long as steepness of slope does not interfere with practical operation. When slopes approach 45 to 50 percent a smaller plow drawn by a single horse should be used.

The use of horses does not involve excessively large investments; the animals are adaptable to practically all slope conditions where trenches can be constructed; and their use maintains better grade in gullied country where numerous sharp turns are necessary.

FINISHING

Finishing operations require a crew of sufficient size to follow reasonably close behind the trenching machines. The following operations are involved: (1) Placing final grade stakes on top of the fill section; (2) finishing the trench to standard dimensions; and (3) placing of equalizers and dams along the axis of the trench.

Grade stakes.—Before finishing operations commence on a roughed-out trench the engineering crew should establish the final grade. Under practical field conditions a long trench may vary in elevation so much that it cannot be finished to the same elevation along its entire length without an excessive amount of hand labor. Under such conditions a rapid preliminary survey with the leveling rod will determine the number of specific elevational units to which the trench must be finished in order to prevent undue hand labor in finishing to zero grade. The trench should be broken into a sufficient number of sections so that sustained cuts or fills by hand of more than 0.3 foot will not be necessary. Under these conditions the maximum elevational differences between trench sections would be 0.6 foot.

The elevation to which each section may be finished with a minimum of hand labor can be determined by averaging the maximum and minimum rod readings of each section of the trench dike. Stakes should then be set at intervals of about 16 feet along the dike of the trench section to be finished to a given grade. The grade line of the dike is next established by marking the stakes with keel at the proper elevation as determined by the rod reading. This procedure calls for the placing of two stakes with different elevations at each point where the trench grade changes. These stakes serve as indicators to the finishing crew as locations for the dams necessary to make each trench section function separately. Trenches constructed in this manner function effectively in checking torrential run-off from rainstorms, but on large snowbank areas the entire trench section which is to function in equalizing melted snow run-off must be constructed on the same grade in order that water may flow along it, if necessary, to adjacent absorbing areas.

Completing to standard dimensions.—With the grade stakes as guides the trenches are finished to the standards shown in figure 1, depending upon the type of trench being used. If the roughing-out process has been done carefully, the principal operation will consist of removing the loose earth from the cut section and placing it in the fill section, the grade stakes being used as guides to maintain the proper grade. Depth and shape are maintained by the use of a templet. Sufficient fill is placed in the dike to permit at least 15 percent shrinkage without reducing the trench capacity below specifications. Where the dike crosses a gully, at least 25 percent excess fill is necessary to compensate for greater settling.

Equalizers.—An equalizer is an earth fill placed at right angles to the trench axis. When finished its top should be at least 0.7 foot wide and 0.3 foot below the lowest point along the top of the trench dike. Equalizers should be placed (1) on opposite sides of small gullies which have been crossed by trenches; (2) at all trench ends that do not terminate at deep gullies (fig. 6); and (3) in the trench at intervals of 20 to 40 feet.

Placing of equalizers along the trench thus breaks it into a large number of small storage units which reduces the hazard in case sections of the dike are destroyed by rodents, by overtopping through faulty construction, or by other causes. They permit water to flow along the trenches from areas of excessive local run-off to contiguous trench sections or to absorbing areas at the ends of trenches.

Dams.—Dams are fills placed at right angles to the axis of the trench, differing from equalizers in that the top is level with the dike fill. Double dams should be placed at vertical-walled gullies, one close to the edge which will probably be destroyed in a short time as the gully walls assume their normal angle of repose, and a second one back from the edge a distance of approximately one and one-half times the gully depth, which will remain intact even after the gully develops graded slopes (fig. 6).

Place dams also at points along the trench where grade changes are indicated by double grade stakes. If dams are not so placed, water will collect rapidly in the low sections, overtop the dikes,

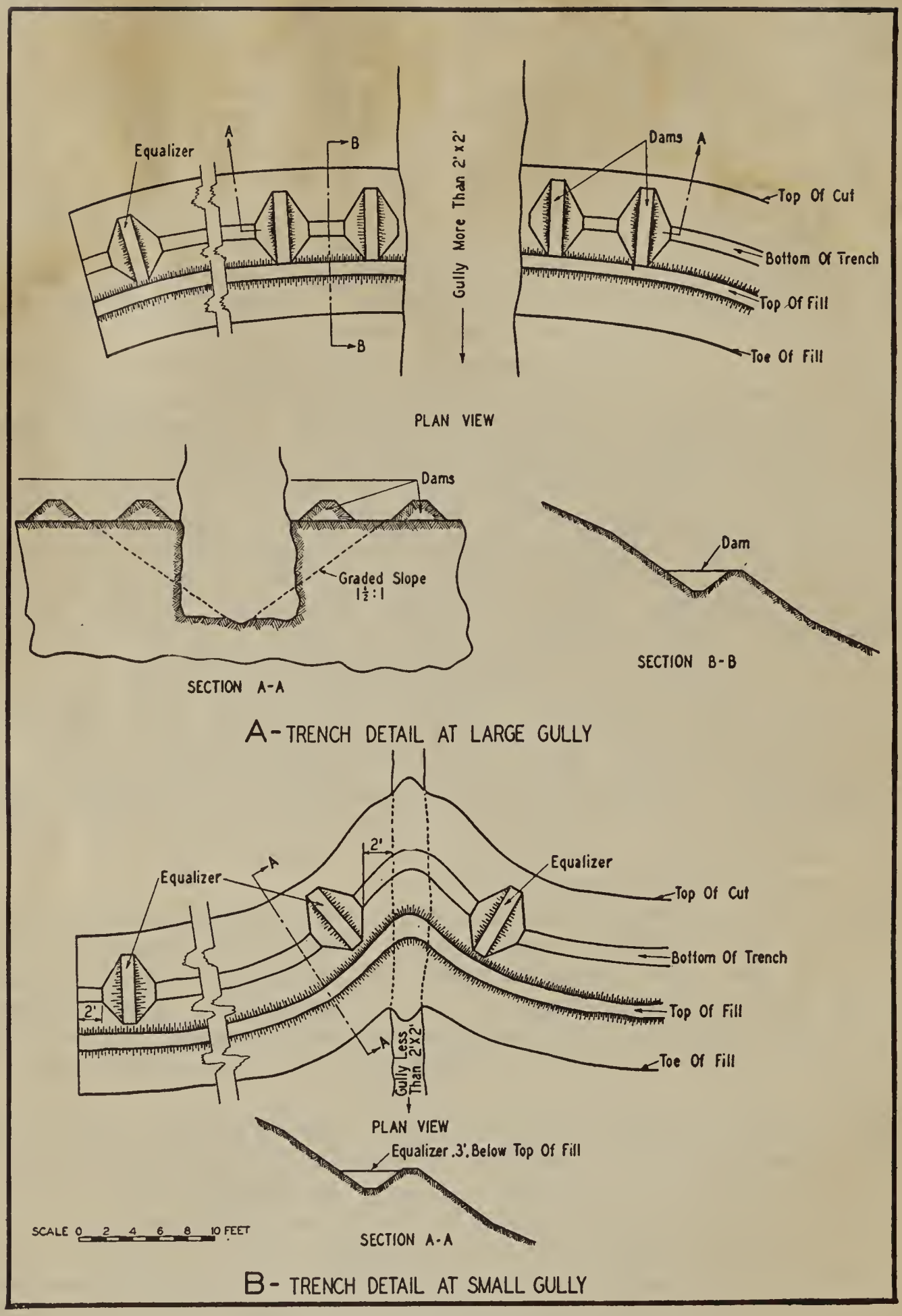


FIGURE 6.—Trench detail at gullies.



F331623 F331621

REVEGETATION IN CONTOUR-TRENCHES THE SECOND SEASON AFTER CONSTRUCTION.

A, Smooth brome and slender wheatgrass are growing in the bottom of the trenches as a result of artificial seeding, while native herbaceous plants have recovered rapidly under complete protection. This area produced excessive run-off during torrential rainstorms prior to the construction of the trench system. Elevation 8,800 feet. *B*, Results of artificial revegetation in a contour-trench within an open aspen stand which was badly depleted of its understory before the control system was built.



F324875

Airplane view of the contour-trench system of flood and erosion control as applied at the head of Parish Creek, Davis County, Utah, near the crest of the Wasatch Mountains.

PLATE 10

destroy other trenches below, and in all probability start new run-off channels which will cut into the soil rapidly.

INSPECTION

Every control unit should be inspected and brought up to approved standards. A method found very satisfactory is to have the foreman and finishing crew accompany the technician on the inspection tour. Weaknesses can be pointed out as they are found and enough men can be left at each point to build the trench to desired specifications. This method also has great value in educating the laborers to the proper kind of trench needed to control run-off and erosion adequately.

REVEGETATION OF TRENCHED AREAS

A comprehensive flood and erosion control program includes definite plans for revegetation of all trenched areas in order that lasting natural methods of control may be substituted for temporary artificial ones (pl. 9). Trenches constructed on steep eroded areas will greatly improve conditions necessary for plant growth by checking surface soil movements and thus providing a more stable seedbed. Available soil moisture is greatly increased in the trenches because snow remains in them about 10 days longer than on contiguous untrenched areas, and each slight summer rain increases soil moisture in the vicinity of the trench as it collects a small amount of surface run-off. These conditions stimulate plant growth to a marked degree.

Whether revegetation will progress under the stimulus of the increased moisture conditions or whether seeding must be done to restore the plant cover are questions that can only be answered after all factors that may affect plant growth on each area are known. In the Intermountain region results indicate that seeding to desirable grasses is generally necessary on depleted areas to restore an effective plant cover in a reasonable time. However, erosion of the soil may have progressed to such a degree that the humic content must be built up through the subclimax plant stages before reseeding with grasses will be effective. If this is the condition, rehabilitation can either be obtained through protection from grazing, which would allow the available plant cover to improve as rapidly as possible, or by transplanting or artificial seeding of some of the local native subclimax species. However, in the absence of data justifying a different procedure, all trenched areas should be seeded to grasses and other herbaceous plants.

Studies in artificial revegetation work show that the important factor in the success of reseeding operations is the proper selection of plants and time of planting to meet the varied climatic and soil conditions of the area involved. Studies made on mountain lands in the Intermountain region indicate that the native plant cover offers a dependable guide in choosing the desirable species to sow. Cultivated species that are to be used must be adapted to the rigorous conditions prevailing on eroded areas. In general, fall is the most favorable season to sow in the Intermountain region, since precipi-

tation is reasonably assured during the early spring when the seedlings are becoming established. However, seeding on trenched areas introduces the factor of loose bare soil, which heaves badly with daily freezing and thawing in early spring after the snow has melted and thus causes an extremely high mortality among the young seedlings. On trenched areas above 7,500 feet elevation it is believed that early spring sowing on snow-covered ground may eliminate both of these objections to some extent, because germination will probably not occur until freezing weather has passed and the young seedlings get the benefit of moisture conditions produced by melting snow and early spring rainstorms.

All available information on seeding of native and cultivated plants under conditions comparable to areas to be trenched should be carefully considered, and, insofar as possible, species, methods, and time of seeding selected should be adapted to the specific conditions of the site involved.

Where timber or brush has played an important part in the past in preventing floods and erosion from what are now critical areas, and where there is only slight chance of reestablishing the stand naturally, the revegetation program should include transplanting to native or other proved related trees and shrubs.

All controlled areas must be protected from livestock grazing during the period of recovery of the vegetation to prevent the destruction of the trenches and to promote the most rapid establishment of an adequate plant cover. This may be done by drift fences to control grazing where large drainages are involved or by completely fencing small spots which have been trenched (pl. 10).

PRECISE WORK ESSENTIAL

The details of the contour-trench system of flood and erosion control as herein presented apply particularly to the conditions that exist on the high range watersheds of the Intermountain region. Here experience has clearly demonstrated that even such small structures as contour-trenches will be successful in checking run-off from torrential rainstorms and melted snow water and in distributing water uniformly on steep slopes, only when constructed on a precision basis.

Precision construction means level trenches of high capacity that will do the job for which they are intended. The slightly higher initial cost is justified by the assurance of success in contrast to the possibility of failure from less careful work. With careful planning, well-organized crews properly supervised, and rigid inspection, such trenches can be constructed almost as cheaply as unlevel trenches of low capacity, which may fail at the very time when they are needed most. Flood and erosion control work will be judged in the final analysis by its effectiveness in preventing soil losses on steep slopes, checking torrential run-off that may result in floods or mud-rock flows, and aiding revegetation.

U. S. GOVERNMENT PRINTING OFFICE: 1937